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Studies of the solar cycle have revealed that the size distribution of active regions does not vary with the solar cycle. Size, rate of rise and lifetime of active regions are roughly proportional although a wide range of variation exists among these parameters. The polar field typically reverses about 2 years after solar maximum. The new solar cycle does not seem to start until after the reversal of the sign of the magnetic poles. However, the new solar cycle does overlap appreciably with the previous cycle and begins 3 or more years prior to the minimum in sunspot producing active regions. The solar cycle begins with ephemeral regions at high latitudes. From the analysis of active region and ephemeral region data over more than a whole solar cycle it is concluded that ephemeral regions are in all respects the small-scale end of the distribution of active regions. No rationale was found for excluding ephemeral regions as one of the effects of the solar dynamo. The search for the early ephemeral regions associated with solar cycle 23 at high latitudes yielded the tentative conclusion that it was detected during our observing runs during the spring of 1993 although confirming data is needed.

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The formation of a filament occurred during an observing run in the late summer of 1990. It was accompanied by an observed large-scale velocity field in which a large area of negative magnetic flux drifted slowly toward an area of positive magnetic flux. The filament formed along the zone of convergence where the cancellation of magnetic flux was observed. This example of the formation of a filament led to the development of a concept of filament formation in active regions. A series of discoveries about the nature of filament channels and filaments ensued. It was found that there are two types of filament channels, sinistral and dextral. It was also discovered that there are also two and only two kinds of filament structure, left bearing and right bearing. Then it was found that sinistral channels always correspond to left-bearing structure and dextral filaments always correspond to right bearing structure. Lastly, it was found that quiescent sinistral-left bearing filaments dominate in the southern hemisphere and that dextral-right bearing filaments dominate in the northern hemisphere. It was established that this pattern does not change with successive solar cycles. The discoveries of the two types of filament structure led to further ideas about the formation of quiescent filaments and the possibility that there is continuous interaction between the filament magnetic field and the small-scale magnetic flux beneath filaments. It was hypothesized and subsequently confirmed that the appendages along a given side of filaments are rooted in small-scale magnetic fields that are opposite in polarity to the network magnetic field on the same side of the filament. Because of this finding it was possible to create a realistic 3 dimensional model representing the magnetic field configuration of a filament that was observed from 15-17 May 1992.

It was found that X-Ray bright points are associated with both converging magnetic fields and cancelling magnetic fields on the quiet sun. A converging flux model was proposed in which there is a critical interaction distance in the corona which will lead to magnetic reconnection in the corona and the birth of an XBP.

Experiments with a LiNbO3 Fabry Perot Etalon proved that this filter is capable of yielding images equal to or better than the best birefringent filters providing care is taken to isolate a single passband by means of prefilters.

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LARGE-SCALE VELOCITY FIELDS AND SMALL-SCALE MAGNETIC FIELDS DURING THE MAXIMUM OF SOLAR CYCLE 22

FINAL TECHNICAL REPORT

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FINAL REPORT - RESEARCH ON LARGE-SCALE VELOCITY FIELDS AND SMALL-SCALE MAGNETIC FIELDS DURING THE MAXIMUM OF SOLAR CYCLE 22

1.0 SUMMARY OF RESEARCH OBJECTIVES AND ACCOMPLISHMENTS:

Our original goal in this program was to gain greater insights into the nature of the solar cycle by acquiring and analyzing data on observable features of the cycle that were least understood. These included:

1. large scale flow fields, detectable in time-series of magnetograms

2. the earliest signs of the solar cycle in the form of small bipolar units of magnetic flux at high latitudes

3. statistical properties of small-scale active regions at all latitudes

4. the interpretation of cancelling magnetic features (how magnetic flux disappears from the solar surface)

5. the reversal of the sign of the polar magnetic field which was expected to occur during the 3-year interval of this research program

We succeeded in learning new information on all of these topics. In addition the Co-Investigator, Karen Harvey, served as Chairperson for the Scientific Organizing Committee for a Workshop on the solar Cycle. The Principal Investigator, Sara Martin served as a member of the Scientific Organizing Committee. Karen Harvey also was the editor of the proceedings of the Workshop which is a Book entitled 'The Solar Cycle', continuing all of the review papers and research papers presented at this Workshop.

We feel that our contributions have substantially enhanced the current body of knowledge on the solar cycle. Although the nature of the solar cycle is still a major astrophysical puzzle, our work through this grant also has served to identify areas on which additional research needs to be focused.

In addition to our solar cycle studies, we made several exciting new findings about:

1. the association ray bright points to photospheric magnetic fields

2. the utility and use of $LiNbO_3$ Fabry-Perot Etalons for solar imaging

3. the nature of filament channels

4. the interpretation of cancelling magnetic fields

5. the magnetic field geometry of filaments

6. patterns in the global distribution and properties of filaments

7. the rooting of the appendages of filaments relative to chromospheric structure and photospheric magnetic fields

Item 1 above refers to the predicted association of x-ray bright points with cancelling magnetic features. However, it was also learned that X-ray bright points can be associated with converging magnetic features of opposite polarity prior to the observation of cancellation between those features. This led to a converging flux model to explain the existence of x-ray bright points.

Regarding the second item above we demonstrated that the Australian made $LiNbO_3$ Fabry-Perot etalons can yield images whose optical quality equaled or exceeds those obtained with the highest quality birefringent filters.

The latter discoveries (items 3-7) also led to a totally new conceptual models for the magnetic field structure of filaments and the formation of filaments.

2. SUMMARY OF ACCOMPLISHMENTS

2.1 STUDIES OF THE CURRENT AND PREVIOUS SOLAR CYCLE

A major study was conducted by Karen Harvey on the properties and emergence patterns of active regions and ephemeral active regions over an entire solar cycle. She analyzed the spatial, temporal, and size distributions of active region and ephemeral active region over 27-29 solar rotations throughout solar cycle 21 from 1975 thru 1986. She also studied the reversal of the polar fields during the last several cycles and performed some studies of the solar irradiance. The results are published in 7 papers listed in Section 4.

One of the interesting new findings about the solar cycle is that the shape of the size distribution of active regions remains nearly constant over the solar cycle even though the numbers of regions varies by as much as a factor of 8 from solar minimum to solar maximum.

The variation of the frequency of emergence of active regions does depend on size. The factor of 8 from solar minimum to maximum applies to regions greater than 3.5 square degrees. For regions less than 3.5 square degrees, the frequency of emergence varied by a factor of 4.7 from solar minimum to maximum. The frequency of emergence of ephemeral regions varied by only a factor of 2 from minimum to maximum.

The tendency for active regions to recur at the same locations is high; 44 percent of all regions over 3.5 square degrees occurred within the boundaries of previous regions. With increasing activity, an increasing percentage of regions occurred outside of active region than within active regions; from solar minimum to maximum, the tendency for new regions to occur outside of active regions rather than within pre-existing active regions increased by a factor of 3.5. This tells us that recurrence is more conspicuous during solar minimum than during solar maximum. Recurrence also increases with region area. Regions larger than 18.5 square degrees most commonly ended their lifetime by the emergence of another bipolar region of at least equal size within the confines of the original region.

Active region size, rise time and lifetime tend to be proportional but there is a wide range of variation.

Results concerning the smallest bipolar regions, known as ephemeral regions, were as follows:

(1) their size ditribution fits smoothly into the size distribution of the larger active regions

(2) their time-dependent properties smoothly merge with those of larger active regions.

(3) their spatial distribution in latitude has the form of a butterfly diagram but with extended wings at high latitides; the wings reveal that the ephemeral regions initiate each solar cycle several years in advance of the systematic appearance of new cycle regions with sunspots.

(4) their numbers vary in phase with the solar cycle although they begin to be detectable about 2 years after the reversal of the solar polar fields and develop a recognizable pattern of emergence at high latitudes within 3 years in advance of solar minimum.

(5) their evolutionary properties are similar to larger active regions

All of these properties are consistent with the conclusion that ephemeral regions are the small-scale end of a broad size spectrum of bipolar active regions.

2.2 THE SEARCH FOR THE BEGINNING OF SOLAR CYCLE 23

During the spring of 1991, three observing runs were conducted simultaneously at Big Bear Solar Observatory and the National Solar Observatory at Kitt Peak. The primary purpose of this observing program was to search for the beginning of solar cycle 23. Our technique at Big Bear was to take successive fields of view from the equator to the pole for 5 consecutive days on approximately the same zone in longitude in one hemisphere. At Kitt Peak similar magnetograms were taken of the same area from the equator to the pole in the same hemisphere.

The data is secondarily useful for following the evolution of a few small active regions which developed in the selected longitude zone.

During the observing run at Big Bear, preliminary analysis was initiated by making a magnetogram movie on an Amiga computer the same night following the day that the data was recorded. This was done during and following the usual night program of replaying the day's magnetograms on a video screen and photographing the images on film. The Amiga version is similar to that one film, but can then be immediately viewed whereas the data on film must be processed and is not available for viewing until many days after the data is taken. The Amiga movies were used to identify the ephemeral active regions which would allow the detection of solar cycle 23 if a band of reversed polarity ephemeral regions could be identified at high latitudes ($> 35^{o}$). No evidence of solar cycle 23 was

found in the preliminary surveys of the data.

During the spring of 1992, sets of data were taken in May and June of 1992 at Big Bear Solar Observatory on a filament at the latitude where new cycle regions were mostly be seen. Concurrent observations were made using the vacuum telescope at Kitt Peak. In the preliminary surveys of this data, no evidence of solar cycle 22 regions were detected.

In May 1993 and October 1993, an attempt was made to repeat the same type of observations as during the spring of 1991. Due to poor weather in May, our data sampling was poor. A follow-up set of observations was also taken in October 1993 although the data samples were also poor due to weather problems and poor seeing. Nevertheless, several reversed polarity ephemeral regions were seen in the May data and it is thought that the new cycle has begun.

It will be important to take additional sets of data in the spring of 1994 to verify that solar cycle 23 is present at moderately high latitudes in the form of ephemeral regions. A few small reversed polarity regions with sunspots have also been seen but they are not occurring on a consistent basis. Hence it is uncertain whether these regions represent the early part of the cycle 23 or whether they are just anomalous regions of solar cycle 22.

This study was effectively conducted and should be repeated approximately once a year until solar cycle 23 is identified. The current data is useful for identifying the latitudinal extent of solar cycle 22 and how much the active region belt shifts in latitude from year to year as a base from which to judge the earliest appearance of solar cycle 23.

2.3 THE ACQUISITION OF NEW DATA SETS

The dates of the joint observing runs at Big Bear and Kitt Peak were:

Fall 1989

27 Sep - 3 Oct	Active Region
25 Oct - 31 Oct	Same Active Region - next rotation
22 Nov - 28 Nov	Same Active Region - next rotation

Spring 1990

12 Apr - 18 Apr	Small Active Region
10 May - 16 May	Area of Previous Small Active Region
7 Jun - 13 Jun	Different Active Region

Fall 1990

28 Aug - 1 Sep	Active Region - Formation of a Filament

Spring 1991

27 Apr - 1 May	Quiet Sun - Start Search for Solar Cycle 23

24 May - 28 May	Continue during Second Rotation
21 Jun - 26 Jun	Continue during Third Rotation

Spring 1992

12 May - 17 May	Filament and Quiet Sun, Solar Cycle 23
9 Jun - 16 Jun	Continue at Same Location during Second Rotation

Spring 1993

14 Apr - 21 Apr	Doppler Shifts and Filament Structure
12 May - 17 May	Quiet Sun and Search for Solar Cycle 23

Fall 1993

23 Oct - 29 Oct	Quiet Sun and Search for Solar Cycle 23

During April, May and June 1992, 7-day observing runs were scheduled at 27-day intervals such that the same area of the sun could be observed during 3 consecutive rotations of the sun. Complementary observations were planned at the National Solar Observatory at Kitt Peak and the Big Bear Solar Observatory by the Co-Investigator and Principal Investigator.

The first objective was to observe the large-scale velocity fields around an active region if a suitable target could be chosen on the dates selected. A second objective was to continue the search for the new solar cycle (23) in the form of ephemeral active regions. A third goal was to record the evolution of filament structure.

During the observing run in April 1992, a small active region was observed but it did not turn out to be the type to exhibit large-scale velocity fields and it decayed rapidly. During 12-17 May, no suitable new active region was present on the sun for the first objective. An area on the quiet sun was selected for meeting the second and third objectives. The second objective was met by observing poleward of the active region belt where ephemeral regions of the next solar cycle would be most likely to occur. The third objective was met by selecting the observing site to coincide with a quiescent filament. Excellent high-resolution observations were obtained. The data is well suited for analyzing the formation and lifetime of the intermediate legs of the filament.

During June 1992, the same filament channel was observed as in May. Excellent observations were again obtained. The filament exhibited a slow partial eruption and reformation. Thus additional data was acquired for the third objective of studying the evolution of filament structure. It was decided that additional observations for the first and second objective would be sought again during the subsequent fall and spring.

2.4 FILAMENT STUDIES

2.4.1 The Formation of Filaments

Filaments (prominences) only form at polarity inversion zones where the magnetic field has the extreme non-potential configuration. We assert from our studies of filaments that filaments almost always form concurrently with the development of the extreme non-potential configuration. However, where magnetic field gradients are extremely high, the filaments can be extremely narrow and sometimes are not obviously present. Nevertheless, the formation of filaments is an extremely reliable indicator of the development of the extreme non-potential configuration. As such they are also the markers of probable flare sites. However, because filaments mark the approximate sites of flare initiation, they also sometimes exhibit a lot of mass motions prior to solar flares and usually erupt during solar flares. It is common for the filament to begin to ascend in the corona within a few minutes to a few hours preceding a solar flare. On the visible hemisphere of the sun, coronal mass ejections are almost always accompanied by the eruption of filaments.

In the context of trying to understand the solar cycle, we are necessarily interested in where and how magnetic flux originates and where and how magnetic flux disappears. The hypothesis that magnetic flux is only expelled from the sun only during coronal mass ejections is of great importance because it is provocative evidence that the key magnetic field changes, associated with the expulsion of magnetic flux, occur at polarity inversion zones.

We believe we have observed and studied an important part of the key magnetic field changes that result in the creation of the extreme non-potential magnetic field configurations and also result in the development of filaments, the occurrence of the most energetic flares, and the expulsion of magnetic flux from the sun. We have accomplished this by studying the changes in the line-of-sight magnetic fields that accompany the development of filaments and solar flares. The important observations are of the 'cancellation' of magnetic flux that occurs when opposite polarity magnetic fields either migrate or are pushed together at polarity inversion zones. This process is described below in the sections on the association of cancelling magnetic fields to solar flares and the formation of filaments. Both are the topics of published research papers under this research program and listed in Section D.

2.4.2. Conditions for the Formation of Prominences (Filaments)

During the final year of this program, an invited research-review paper was prepared by S.F. Martin for the IAU Colloquium on Prominences held in Hvar, Yugoslavia, September 1989.

In this paper, the phenomena most commonly observed during the formation of Prominences are reviewed. It is then proposed that 3 of the conditions are essential to prominence formation: (1) the existence of a coronal magnetic field arcade connecting the opposite polarity fields, (2) the convergence of opposite polarity magnetic fields under the arcade and (3) the cancellation of these fields. It is hypothesized that the persistence of these conditions for a

sufficient length of time will invariably result in the formation of a prominence. The research review includes illustrations of all of the conditions associated with prominence formation.

This is the first paper to propose a set of necessary and sufficient observational conditions for prominence formation. The paper also gives some insight into possible causes of prominence eruption. It suggests that the same conditions that lead to prominence formation also eventually result in the eruption of a prominence due to the continued build-up of the horizontal component of the magnetic field of a prominence after its formation.

2.4.3. An Observed Example of the Formation of a Filament

An observing run initiated by S.F. Martin and J. Zirker in August of 1990, provided an extraordinarily good example of the formation of a filament. The observations were taken at the Sacramento Peak Observatory and Big Bear Solar Observatory from 28 August thru 1 September 1990. Analyzing this data during FY1991 led to the formulation of a new concept for the formation of filaments. The new concept of how filaments form was presented as a poster paper at the IAU meeting in Buenos Aires in July 1991.

In the August 1990 example, the formation of a filament coincided with the cancellation of magnetic fields of opposite polarity which migrated together. The migration of the fields was evident over the entire 5 day interval of observation. The filament formed by the beginning of the third day. The network fields which migrated together and cancelled were clearly not the end points of field lines which form an arcade over the filament channel. Instead the end points were at opposite ends of the filament channel. Hence the cancellation was taking place between separate bipolar magnetic fields. The migration of the flux caused the separate bipolar fields to move together sideways instead of end to end.

The motion of the opposite polarity fields together would then have to result in magnetic reconnection. The reconnection was thought to be low in the solar atmosphere because the chromospheric fibrils revealed that the fields which had migrated together were tilted in opposite directions with respect to vertical. In this configuration, the consequence of the reconnection would be for field lines to rise from near the photosphere into the corona. Many such reconnections would then build a concentrated magnetic field along the polarity inversion between the separate bipolar magnetic fields. Each reconnection would result in bringing some mass from the chromosphere or photosphere into the corona. Eventually the accumulation of mass would reach the critical density at which cooling would take place. The formation of the filament would then be seen as the apparent condensation of filament mass along the filament channel.

This concept of the formation of filaments differs from all previous theories in two fundamental respects. First, rather than being formed within a bipole, the formation takes place between separate bipolar fields. Secondly, the mechanism of magnetic reconnection, only invoked in two other models, differs in this concept by its occurrence at or near the photosphere.
The disappearance of magnetic flux, as it is observed to cancel, is explained as

the upward transport of magnetic field from a layer of the solar atmosphere at or below the level at which the magnetic fields are detected. That level is slightly above the photosphere because the observations are taken in the wing of a magnetically sensitive spectrum line.

An abstract describing this process of filament formation is published in the Proceedings of IAU Colloquium 133 on Eruptive flares held in Iguazu Argentina, August 1991.

This above model is significant departure from all other filament models in that energy is extracted from the photosphere and deposited in the corona at the time of observation of the cancelling magnetic fields. This model, however, best fits filaments in active regions which are low and have relatively sharp edges.

It was considered that quiescent filaments must invoke either different or additional processes in their formation. Our discovery of the two magnetic types of filament channels and filaments and the two corresponding structural types of filaments (sinistral and dextral), gave the clue that filaments might be related to the random component of magnetic fields associated with ephemeral regions and supergranules, rather than just the network magnetic fields as assumed for all theoretical models of filaments. S. Martin developed a hypothesis that the interactions of small-scale magnetic features below filaments on the quiescent sun was the key to understanding the sinistral and dextral structure of filaments. She also formulated the hypothesis that these interactions would result in the appendages along the sides of filaments being connected to small-scale magnetic fields opposite in polarity to the network magnetic field on the same side of the filaments. This hypothesis then would explain the mysterious 'normal' and 'inverse' categories of filaments whose discovery and study began about 15 years ago by LeRoy and colleagues from Observatoire de Paris at Meudon.

2.4.4. Developing a Scale Model of a Filament

During the summer of 1993, S. Martin and a student summer assistant, Christopher Echols, began the study of the filament observed during May 1992. One objective was to measure the true dimensions of the filament (height, length and width) of the filament and to produce a scale model. Another goal was to try to find the locations of the footpoints of the side appendages in the chromosphere and photosphere. Both goals were achieved.

The filament was found to be approximately 250,000 km long with an average height of 33,000 km. The width is variable from a thin sheet to about 20,000 km wide between the footpoints on either side of the filament. The height varied from about 30,000 to 50,000 km.

Two significant new associations were made with the footpoints:

1. In the chromosphere, it was found in a few frames of very good seeing that the fibril pattern at the footpoints has a directional pattern that is reversed from the network on the same side of the filament but the same as the pattern of the network fibrils on the opposite side of the filament except much smaller. This was the first clue that the rooting of the appendages was in magnetic field

opposite in polarity to the network on the same side of the filament.

2. In the photosphere, it was found that the appendages for the larger footpoints were associated with magnetic fields opposite in polarity to the network on the same side of the filament. The errors in overlaying the H-alpha images and the magnetograms was such that the positions of the thinnest appendages could not be known with certainty. However, in all cases, there was always in the approximate vicinity of the end off the appendage, a feature of opposite polarity.

The finding about the footpoints and their association with photospheric magnetic fields, now allows us to conceive of the magnetic field of quiescent filaments as being similar to active region filaments. The principal difference is the addition of appendages which form along the sides of filaments in association with the continuously changing magnetic fields beneath these filaments. In addition the observations show that each end of the filament is clearly rooted in network magnetic field of opposite polarity. With the amount of information learned, it was then possible to construct a model of the magnetic field of a filament making just two assumptions:

1. that the magnetic field lies parallel and only parallel to the fine structure of the filament

2. that the footpoints of the thin appendages are rooted in opposite polarity magnetic field similar to the large appendages.

The magnetic field geometry of the filament is depicted in Figure 1 by means of a wire model representing the magnetic field lines. A top and side view are shown. The southeast end (upper right) is in positive polarity network while the northwest end (lower left) is in negative polarity network. The appendages along both sides of the filament are related to small inclusions of magnetic field opposite in polarity to the network magnetic fields. All field lines from the appendages enter or exit the main axis of the filament magnetic field and extend to the opposite polarity magnetic field at the ends of the filament. Some field lines also extend the full length of the filament. The form of the conceived magnetic field is thus very simple. It consists of an axial field running the full length of the filament with some field lines appearing to be frayed along each side such that they connect to small-scale magnetic fields of opposite polarity to the network on each side of the polarity inversion beneath the filament.

A single copy of the 3-dimensional scale model of the filament will be submitted to the grant technical monitor as part of this final report.

2.5 EXPERIMENTS WITH A LITHIUM NIOBATE ETALON

During the fall of 1990, experiments were continued using the $LiNbO_3$ etalon loaned by D. Rust. Dr. Rust came to Big Bear for a 4-day visit to initiate the first observations of magnetic fields using the $LiNbO_3$ etalon. Magnetograms were successfully obtained having sensitivity and resolution comparable to the magnetograms usually taken at Big Bear with Zeiss 1/4 birefringent filter.

Fig. 1. Top and side views are shown of this schematic 3D model of the magnetic field of a filament. Wire is used to represent the field lines which are shown in relation to the photospheric magnetogram mounted on cardboar : The representative field lines depict the rooting of the magnetic field of the appendages of the filament in small patches of magnetic flux opposite in polar , to the network magnetic field at the sides of the filament. White and light . indicate positive polarity; black and dark gray, negative polarity.

However, the magnetograms taken using the $LiNbO_3$ etalon were more non-uniform. There are three possible sources of the non-uniformity. First is the KDP crystal; some non-uniformity is always present from this source even in the daily magnetograms taken at Big Bear. Second is the prefilter; an extremely narrow prefilter is required for best results and the ideal prefilter was not available. The third source of non-uniform images can be the configuration of the optical system in which the filter is placed. The high f-ratio required for the etalon was used; however, there was limited space on the optical bench of the telescope for changing the optical configuration. Possible further experimentation was discussed for the future.

In spite of the non-uniform images during obtained during these few days of testing the etalon, the quality of the images and the throughput of light make this filter the best one available today for acquiring improved magnetograms. The experiments conducted were only of the line-of-sight component. The etalon is even better suited for acquiring transverse magnetograms because of its narrow profile. Additionally, magnetograms taken with a $LiNbO_3$ etalon can be more easily and accurately calibrated than the magnetograms taken with a birefringent filter.

After experimenting with magnetograms, the etalon was then set-up with various H-alpha pre-filters loaned by Del Woods of the Daystar Filter Co. The Daystar prefilters were not adequately uniform in their passbands to yield good results. Also transmission of these filters as prefilters was lower than desired. The best prefilter was a 3A prefilter manufactured by the Andover Corporation. Very good H-alpha images were obtained. However, even this narrow prefilter did not completely block all of the light from one of the adjacent passbands of the etalon.

The main visual difference from the birefringent filter images was that the sunspots were more completely visible; this indicates that a small component of photospheric light was being transmitted by the adjacent passband. For further improvement, experimentation was done using a single birefringent element tuned to eliminate the light from the adjacent passband. This worked very well. Consequently, a special birefringent element of the appropriate thickness of calcite was made for the next set of experiments in November of 1990.

The final experiments using the narrow prefilter (3A) and the birefringent element along with the $LiNbO_3$ etalon gave excellent results. Comparison was made with images taken the same day through the best Zeiss birefringent filter on the same optical bench. In every respect the images obtained with the $LiNbO_3$ etalon and prefilter were as good or better than those obtained with the birefringent filter. The contrast was slightly better in the images obtained through the $LiNbO_3$ etalon.

In summary, it is concluded that the $LiNbO_3$ etalons with appropriate prefiltering are extraordinarily useful filters for numerous types of solar observations and research.

2.6 OBSERVATIONS AND INTERPRETATIONS OF X-RAY BRIGHT POINTS

An analysis of X-Ray bright points and corresponding magnetic features revealed many new associations and confirmation of the deduction of K.L. Harvey that XBPs are associated with the encounter of small-scale opposite polarity magnetic features. The original conclusion was indirectly found by using 10,830 dark points as proxies for X-ray bright points. K.L. Harvey demonstrated a strong and convincing association of dark points with encounters of small-scale opposite polarity magnetic features. She then concluded that there must also be a similar association with XBPS because of her previous finding of an association of dark points with XBPs. Our study also confirms this earlier finding. However, in the our study, it is found that XBPs are associated with a variety of small-scale magnetic features. Most of these were cancelling magnetic features. A few XBPs were associated with ephemeral regions but most ephemeral regions were not associated with XBPs. Most of the ephemeral regions that were associated with XBPs were also had cancelling components. A few XBPs were associated with magnetic features that were converging but were not yet cancelling. However, nearly all cancelling magnetic features are also converging. Consequently, it was concluded that the convergence of flux of opposite polarity was the stronger and more fundamental association.

A model of XBPs based on flux convergence was published by E.R. Priest, C.E. Parnell and S.F. Martin. The model consists of three phases: a Preinteraction Phase, an Interaction Phase, and a Cancelling Phase. The XBP is initiated in the corona between the approaching magnetic fields of opposite polarity. Magnetic reconnection depends on the proximity of features and is referred to as the *interaction distance*. That distance critically depends on the magnitude of the approaching magnetic flux fragments.

In the above scenario, the XBP is initiated before the cancellation begins. The XBP is not necessarily still visible when the cancellation occurs; to explain the observations, either the site of reconnection must drop to the photosphere or the reconnection at the at the photosphere is independent of the X-ray emission in the corona.

Recently, K.L. Harvey has confirmed these results by studying XBPs observed by the Yohkoh satellite.

In summary, we suggest that most XBPs form when converging flow brings oppositely directed field lines together, leading to reconnection and heating of the newly-formed loops in the low corona.

2.7 ON THE INTERPRETATION OF CANCELLING MAGNETIC FIELDS WITH SOLAR FLARES

A Contribution to the Flares22 Workshop (Preflare Team) by S.F. Martin

Cancelling magnetic fields are defined as the observed disappearance of magnetic flux of both polarities at the boundaries between closely spaced magnetic features of opposite polarity as seen in magnetograms of the line-of-sight component. The spatial association of solar flares to cancelling magnetic fields was first noted by Martin, Livi, and Wang (1985) and was more explicitely discussed in relation to other preflare changes by Livi et al. (1989). From first observations, it was pointed out by Martin, Livi and Wang that the initia sites of flares straddle sites of cancelling magnetic fields but the flare emission then often spreads into other areas where there are no cancelling magnetic fields. They proposed an indirect relationship because flares also occur impulsively (or as a rapid succession of discrete bursts) while cancelling magnetic fields are relatively slow, evolutionary magnetic changes that exist before, during, and after flares. Although the temporal scale of flares and cancelling magnetic features differ, the complete absence of a physical relation relationship between them cannot be assumed either; no flares have been shown to occur in the absence of cancelling magnetic fields when adequately sensitive magnetograms have been acquired (Livi et al. 1989). Additionally Livi et al. discuss how cancelling magnetic fields are the only observed factor in common among flares with and without shear flow, with and without the presence of emerging magnetic flux, and with and without various other parameters related to some but not all flares. Specifically, the 'evolving magnetic features' described by Martres et al. (1968), where adjacent magnetic fields are concurrently growing and shrinking, are readily interpreted as identical with more recent and higher resolution observations of emerging flux which is cancelling with adjacent flux of opposite polarity.

Martin and Livi (1991) suggested that the link between cancelling magnetic fields and flares can begin to be understood for the category of flares designated as 'eruptive flares' (Svestka 1991) which are associated with the concurrent eruption of filament magnetic fields and coronal mass ejections (CMEs). They suggest that cancelling magnetic fields are linked directly with the formation and maintenance of filament magnetic fields and hence indirectly to the eruptive flares. They propose the filament magnetic field is a principal site of energy storage for the flare. In their view, the cancelling magnetic fields are a visible manifestation of part of the process in which energy is extracted from the very low solar atmosphere, reconfigured, and stored at the sites of filament magnetic fields. They point out the continuous nature of that process and its relation to filament formation. There is now substantial evidence that filament formation does not cease as long as cancelling magnetic fields are present (Martin 1990). Even the eruption of the magnetic field and initiation of a flare in the upper part of a filament channel does not interrupt the continued formation of additional new filament magnetic fields in the lower parts of the same channel. Their main conclusion was that cancelling magnetic fields can represent the direct transfer of magnetic flux, and therefore energy, from the photosphere into the corona.

Martin (1991) described a scenario for the formation of filament that accomplishes the transfer of magnetic field from the photosphere into the corona

The filament and filament magnetic field in the corona marks the site of the resevoir of magnetic field energy that can be released by rapid magnetic reconnection in the corona. As in various amplifications of the Kopp and Pneuman model (1976) as reviewed by Svestka (1991), the bright 'flare' emission is part of the released energy in the low corona and chromosphere below the reconnection points. The CME is the released magnetic field above and around the reconnection points. (The release of the magnetic field concurrent with the flare does not preclude the possible existence of other evolutionary factors that might also contribute to the build-up to that release.)

Thus, cancelling magnetic fields are proposed to be directly related to the formation of filament magnetic fields. It is the presence of a continuously building magnetic field in the coronal part of the filament channel that is significant and not necessarily the presence or lack of presence of cool filament mass in those channels. Harvey (1993 personal communication) has observed that the eruption of highly fragmented and barely visible quiescent filaments in 10,830 A Spectroheliograms. These events take place in the same way and produce the same effects as the eruption of highly visible filaments. The occurence of an eruptive flare is then directly related to the stability of the filament magnetic fields and surrounding coronal magnetic fields. The cancelling magnetic fields are important because they are related to a process of build-up of a resevoir of energy in the corona but, in our current understanding, they do not signify when that energy will be released from the resevoir.

Not all interpretations of cancelling magnetic fields lead to the formation of filament magnetic fields or the build-up of a resevoir of stored magnetic energy.

The interpretations of disappearing magnetic *fields (cancelling magnetic fields)* published to date, are illustrated in (A) through (D) of Figure 1. (A), (C) and (D) are after Zwaan (1985, 1987) and (B) is from Spruit, Title and van Ballegooijen (1987). All schematically show how magnetic flux has been imagined to disappear by either upward or downward transport of magnetic flux through the atmospheric layers represented in the magnetograms. In this diagram, the horizontal line represents the layer of atmosphere of the magnetograms rather than the photosphere so that the diagram can be related to flux disappearance observed in magnetograms recorded in any spectrum line.

The magnetic signal recorded and detected in the wing of spectum lines apparently represent layers of the solar atmosphere between the photospheric densities of 10^{16} and chromospheric densities of 10^{11}. The appearance of flare kernals having densities of the order of 10^{11} to 10^{12} in filtergrams or spectroheliograms from which magnetograms are constructed, provide evidence that the magnetograms represent the solar atmosphere at the top of the photospheric/chromospheric transition zone. Polarity reversals observed in 6103A magnetograms as illustrated by Wang (1993 and these proceedings) also indicate that the magnetograms represent the upper part of the photospheric/chromospheric transition region because these reversals are nearly the same as the polarity reversals observed in H-beta magnetograms.

All of the interpretations summarized here explain the disappearance of magnetic flux in adjacent and opposite polarity magnetic fields as the transport of magnetic flux through the atmospheric layers represented by the magnetograms.

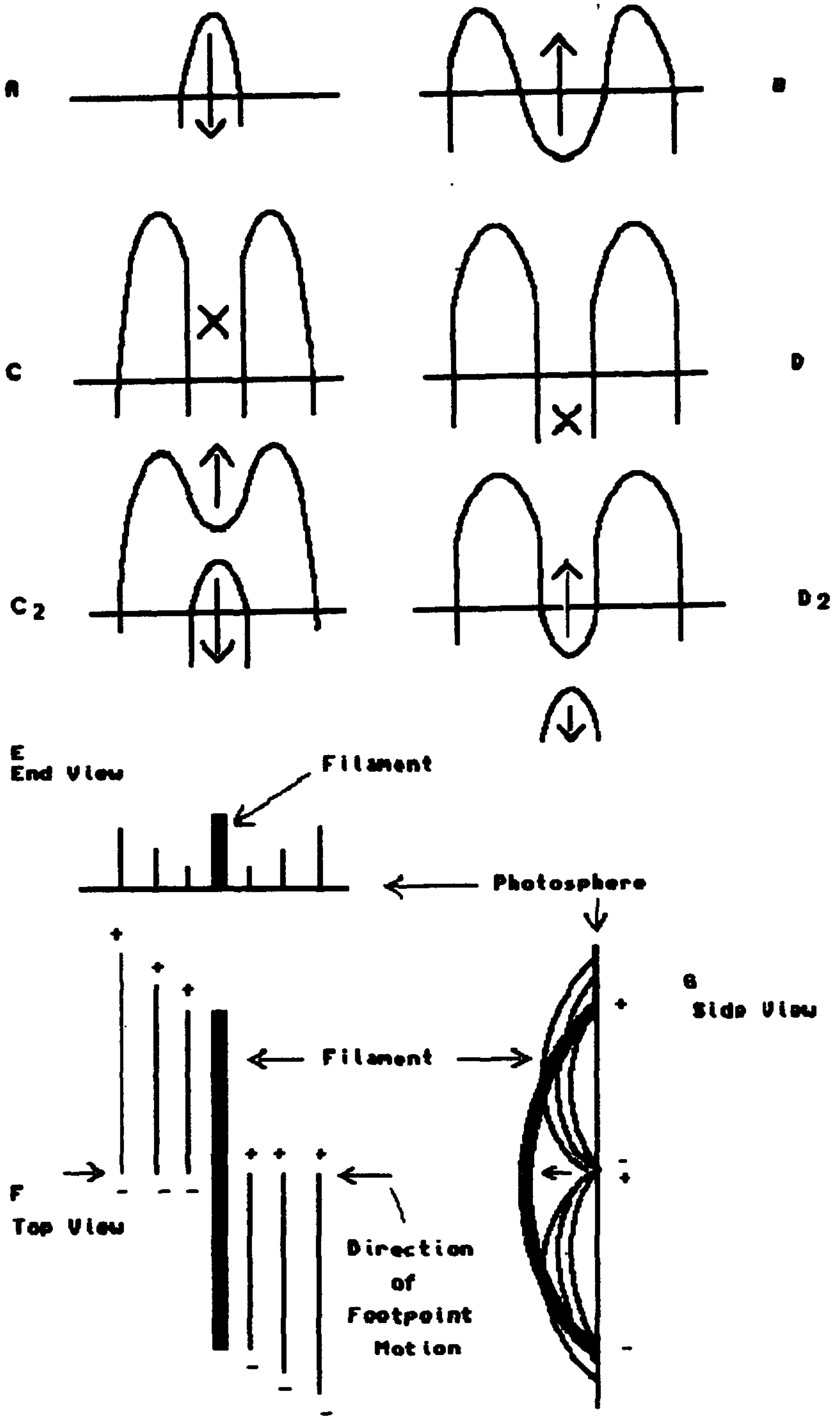

Fig. 2. Schematic drawings on ways that magnetic flux can disappear from the photosphere are shown in A,B,C,D. E,F, and G are end, top and side views of a magnetic field configuration representing the concurrent formation of a filament magnetic field by means of magnetic reconnection near the photosphere which also accounts for the observations of cancelling magnetic flux.

The four interpretations are:

(A) simple submergence of an inverted U-shaped loop
(B) upward retraction of a U loop
(C) submergence immediately following magnetic reconnection above the magnetogram and between separate loops
(D) upward retraction immediately following magnetic reconnection below the magnetogram and between separate loops

There is little or no evidence for simple submergence except possibly in the case of cancellation between strong sunspot magnetic fields as proposed by Gaizauskas (this paper). Wang (1992) has also suggested the upward retraction of U loops as an explanation for the disappearance of sunspot magnetic fields. These interpretations however, do not satisfactorily explain magnetic flux disappearance beneath filaments. In most circumstances the opposite polarity magnetic fields of cancelling magnetic features are not connected by fibrils. Instead they often are divided by filaments both on the large scale and the fine scale. The presence of filaments in active region magnetic fields is evidence against both simple submergence and submergence following magnetic reconnection as depicted in Figure 2(A) and (B) in or above the chromosphere. This is because the magnetic field within active region filaments is horizontal and predominately along the filament as illustrated from H-alpha structures by Foukal (1971) and Martin (1990) in agreement with direct observations of the magnetic fields in prominences (Rust 1967, Le Roy 1988). Circumstance (A) or (C) would require submergence across the magnetic field of the filament or the filament channel. This would be impossible because magnetic field reconnection would occur before the submergence; the field would be reconfigured rather than submerged.

Also because filament channels are built rather than destroyed concurrent with the cancellation of magnetic flux at their base, neither 1A or 1C are compatible with the observations flux cancellation and filament formation described by Martin (1990). Even in the interpretations as drawn in Figures 1B and 1D, simple upward retraction or upward retraction following magnetic reconnection would also require that the upward moving flux loop cut across both the channel magnetic field and the filament magnetic field. Therefore none of the 2 dimensional representations in (A) through (D) adequately depict flux cancellation beneath filaments. This is a major inconsistency between observations and the models of filament formation based on cancelling magneetic fields as proposed by van Ballegooijen and Martens (1989) and Kuijpers (1990).

A way out of this dilemna was proposed by Martin (1991) by considering 3-dimensional aspects of filament channels. From many observations of the fibril structure around filaments and filament channels, Martin proposed the 3-dimensional configuration represented by the 3 views in Figure 1 (E, F and G). The top view of this configuration was already illustrated as a possibility by Rompolt and Bogdan (1986).

The cross section across a filament channel is shown in (E), and the top view and corresponding side view are shown in (F) and (G). (E) through (G) show that the magnetic field is horizontal (perpendicular to the page) in (E) in the channel and along the polarity inversion. The magnetic field in the channel immediately adjacent to the filament is also nearly horizontal as shown by Foukal (1971).

Fibril and spicule observations near filaments confirm the nearly horizontal field lines near the polarity inversion as depicted in (G). With increasing distance from the channel, the magnetic field becomes more vertical.

The arrows in (F) represent the observed direction of slow convergence of the magnetic field toward the polarity inversion during filament formation, as observed (review by Martin 1990). Magnetic reconnection is then expected to occur as the opposite polarity fields migrate together or are brought together by convective motions. The absence of vertical fields near the polarity inversion mitigates against the occurrence of magnetic reconnection in the corona. Since the disappearance of magnetic flux is observed to be slow and steady rather than bursty, it is suggested that it is due to magnetic reconnection occurs in the photospheric/chromospheric transition zone beneath the level of the atmosphere represented by the magnetograms. In the configuration shown in Figures 1(E) through (G), the reconnection low in the solar atmosphere results in nearly horizontal loops or threads joining and springing upward (dashed line) into the low corona to form the longer threads of the filament magnetic field. By many successive reconnections, the filament magnetic field is built. Its nearly horizontal configuration is suggested to be due to the establishment of an equilibrium with the overlying arcade magnetic fields in the corona high above the filament (Antiochos, 1993).

This interpretation simultaneously accounts for both the cancelling magnetic fileds and the formation of filaments in a way that is completely consistent with the observed structure of filament channels. In this simple representation, it accounts for the formation of active region filaments. Additional conceptual stages are required to account for all of the observed structure of quiescent filaments.

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3.0 ABSTRACTS OR SUMMARIES OF RESEARCH PAPERS

3.1 ELEMENTARY BIPOLES OF ACTIVE REGIONS AND EPHEMERAL ACTIVE REGIONS

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Abstract

Elementary bipoles are the substructures of active regions and ephemeral active regions identifiable during the regions' birth and early development. The smallest ephemeral regions appear to consist of only a single elementary bipole. Many ephemeral regions, however, appear as a compact series of several successively forming elementary bipoles. The magnetograms reveal no clear distinction between large ephemeral regions and small active regions except that in small active regions more elementary bipoles appear simultaneously and for a longer interval of time. Medium and large active regions usually consist of several systems of simultaneous and successively forming systems of elementary bipoles.

Systems of elementary bipoles are the source of arch filament systems observed in H-alpha filtergrams. The majority of the arch filaments are aligned parallel to the axes of the associated elementary bipoles. The opposite polarities of elementary bipoles often appear to stream to the opposing ends of previously formed arches as first described by Frazier (1972). However, in the videomagnetograms acquired at Big Bear Solar Observatory, elementary bipoles, with random or reverse orientations with respect to the original pairs, are also commonly observed. These anomalously oriented elementary poles often encounter and cancel with other elementary poles or pre-existing magnetic features, resulting in localized reductions in the line-of-sight component of magnetic flux. Because of the cancellations, the total magnetic flux of an active region, measured at any given time, can be appreciably less than the total flux that has emerged.

3.2 THE EVOLUTION AND ORIENTATION OF EARLY CYCLE 22 ACTIVE REGIONS

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Abstract

The evolution of six major active regions which appeared during the first phase of the present solar cycle (cycle 22) has been studied. It was found that the northern hemisphere regions exhibited a broad range of evolutionary behavior in which the commonly accepted "normal pattern" (whereby the follower flux moves preferentially poleward ahead of the leader flux) is represented only at one end of the range. At the other end of the range, the leader flux is displaced poleward of the follower flux. In the latter cases equatorward extensions of the polar coronal hole are noted.

While it is emphasized that some of the regions in this study follow the more conventional pattern and that all regions in this study emerged during the early phase of cycle 22, the implications for theories of the solar polar field reversals are noted.

3.3 CONDITIONS FOR THE FORMATION OF PROMINENCES AS INFERRED FROM OPTICAL OBSERVATIONS

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Abstract

In the optical region of the electromagnetic spectrum, the conditions most frequently associated with the formation of prominences are: (1) the existence of opposite polarity photospheric magnetic fields on opposing sides of a prominence, (2) a coronal arcade that connects the magnetic fields on opposing sides of a prominence, (3) a transverse magnetic field configuration in the chromospheric and photospheric polarity inversion zones that is approximately perpendicular to the direction of maximum magnetic field gradient between adjacent patches of opposite polarity, line-of-sight magnetic flux, (4) in active regions or decaying active regions, the alignment of chromospheric fibrils in a polarity inversion zone approximately parallel to the transverse magnetic field component and parallel to the long axis of the future prominence, (5) the long-term (hours to days) converging flow of small patches of opposite polarity magnetic flux towards a common polarity inversion zone, and (6) the cancellation of encountering patches of magnetic flux of opposite polarity at a photospheric polarity inversion boundary (interpreted as the transport of magnetic flux out of or into the photosphere). Because these are observed conditions found from magnetograms and filtergrams at various wavelengths, they do not necessarily represent independent physical conditions. Although none of these conditions have proven to be individually sufficient for prominence formation, a combination of 3 of these conditions might prove to be both necessary and sufficient. The following hypothesis is offered for study and evaluation: condition (2) and the combination of conditions (5) and (6), if dynamically maintained for a sufficient length of time, will invariably result in the formation of a prominence.

3.4 DO CHANGES IN THE PHOTOSPHERIC MAGNETIC NETWORK CAUSE THE 11-YEAR VARIATION OF TOTAL SOLAR IRRADIANCE?

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Abstract

Changes in the area of the photospheric magnetic network over the sunspot cycle have been put forward as the "missing component" required to explain the 11-year variation of total solar irradiance observed by space-borne radiometers. We show that this explanation is consistent with recent measurements of the photometric contrast of magnetic faculae, and with our measurement of the network area change during cycle 21.

3.5 CHANGES IN THE PHOTOSPHERIC MAGNETIC NETWORK AS RELATED TO THE 11 YEAR VARIATION THE TOTAL SOLAR IRRADIANCE

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ABSTRACT.

This paper describes a study (a) of solar magnetic fields, using the synoptic magnetic field maps made for each Carrington rotation by the National Solar Observatory since 1975, and (b) of the relation of the magnetic fields to Sun-as-a-star measurements at four wavelengths and by ACRIM. The variations of the active-region and quiet-Sun magnetic fields and of the total Sun are determined during the period covering cycle 21 and the rise of cycle 22. The total magnetic flux on the Sun increases by at least a factor of 4 to 5; the quiet component of the magnetic fields show a factor of 2 or less increase during the same period, compared to the more than 20-fold increase in the active-component magnetic fields. The relation of the active and quiet components of the magnetic fields with 10.7 cm radio flux, 1-8A X-ray flux, He I 10830A equivalent width, Lyman -alpha, and ACRIM measurements was investigated using data averaged over a solar rotation. The 10.7 cm radio flux correlates well with both the Sun's total magnetic flux and the active-region magnetic fields. The correlations with the X-ray, He I, Ly-alpha, and ACRIM data suggests the possibility of a hysteresis as a function of the cycle and cycle phase. During cycle 21 compared to the rise of cycle 22. Some of the hysteresis might be explained by calibration uncertainties in these data sets. No hysteresis is found in the magnetic field data. The results of this study indicate a more complex relation exists between emission sources and the magnetic field than is considered within the scope of this study.

3.6 THE ROLE OF CANCELLING MAGNETIC FIELDS IN THE BUILD-UP TO ERUPTING FILAMENTS AND FLARES

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Abstract

We present a scenario for understanding the role of cancelling magnetic fields in the build-up to eruptive solar flares. The key intermediate step in this scenario involves the formation of a filament magnetic field in the corona above a photospheric polarity inversion where cancelling magnetic fields are observed. The formation of a filament magnetic field is accomplished in several recent models by first interpreting the cancelling fields as a visible effect of a slow, steady magnetic reconnection. This reconnection results in a reconfiguring of the magnetic field; line-of-sight pairs of closely-spaced opposite-polarity fields disappear from the photosphere thereby accounting for the cancellation; simultaneously the horizontal component is increased in the corona above the polarity inversion. The new and increasing horizontal component is synonymous with the building of a magnetic field where mass can accumulate to form a filament. If the magnetic reconnection continues for a sufficient length of time, the changing equilibrium between the growing filament magnetic field and the overlying, coronal magnetic field will result in a very slow, simultaneous ascent of both the filament magnetic field and the overlying coronal magnetic field with greater motion in the outer, weaker coronal field. This upward stretching of the magnetic fields eventually results in a closer spacing of oppositely-directed coronal magnetic fields (resembling a tangential discontinuity) beneath the filament. As depicted in some flare models, magnetic reconnection then suddenly occurs in the corona beneath the filament; flare loops form in the lower part of the reconnected field and a coronal mass ejection and erupting filament comprise the upper part of the reconnected field. To illustrate the observable phases of this scenario, we describe the build-up to two simple eruptive flares in a small active region.

3.7 THE CYCLIC BEHAVIOR OF SOLAR ACTIVITY

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ABSTRACT

Using observations of cyclic phenomena, the solar cycle is discussed to re-assess the onset and duration of an extended activity cycle. It is well known that the first sunspots of a new cycle appear before sunspot minimum and continue to emerge for 12 or more years, ending after the following minimum; the period of time over which activity of a specific cycle is observed is called the extended activity cycle. This paper considers other data on bipolar magnetic regions that places the onset of a cycle earlier than the first new cycle sunspots and extends the period over which activity of a cycle occurs. This includes properties that define the cycle membership of emerged bipolar regions, such as the bipole orientation of active regions and ephemeral regions as functions of their latitude distribution and size. Also discussed are several phenomena other than bipole emergences that have been interpreted as evidence for the onset of a cycle near the time of the reversal of the polarity of the polar magnetic fields.

It is concluded that the best indicator of new cycle activity is the occurrence of bipolar magnetic regions. The uncertainties in the observations and the interpretation of other cycle phenomena make it difficult to define the start and end of extended cycle activity any earlier or later than can be done by observations of magnetic bipoles.

Based on observations of bipolar magnetic regions, the onset of new cycle activity begins with the appearance of ephemeral regions and small active regions about 2.5 to 3.5 years before the statistically defined cycle minimum. These regions have the preferential orientation of the new cycle and are seen initially over a latitude range from 40 to about 60 degrees. Large sunspot regions start to appear 1 to 2 years later. Bipolar magnetic regions continue to emerge over a total interval of 14 to 15 years, the last regions appearing about two years after sunspot minimum. For these data, the overlap between two cycles is about 5 years. There is no evidence of new cycle bipoles emerging at high latitudes before the polar reversal. The first magnetic regions of a new cycle, in fact, do not emerge until almost three years following the completion of the polar reversal.

3.8 THE SOLAR CYCLE PATTERN IN THE DIRECTION OF THE MAGNETIC FIELD ALONG THE LONG AXIS OF FILAMENTS

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Abstract

We confirm the existence of a solar cycle pattern in the dominant east-west directions of the horizontal component of the magnetic fields in polar crown and sub-polar crown filaments. A given pattern is defined for the intervals between successive 11 year reversals of the polar magnetic fields, from roughly one solar maximum to the next. For the interval between the maximum of solar cycles 19 and 20, the horizontal component of the magnetic field along the long axis of the filaments of the northern polar crown were directed generally westward and those of the southern polar crown were generally directed eastward (Rust, 1967). The dominant east or west direction of the first tier of sub-polar crown filaments was also found by Rust to be opposite to that of the polar crown. It was confirmed by LeRoy (1983) that these patterns changed east for west and west for east during the interval between the maxima of solar cycles 20 and 21. We verify the continuation of these reversals of the dominant east-west directions of the magnetic fields in polar crown and subpolar crown filaments for the intervals between the maxima of solar cycles 21-22 and 22-23. The pattern is consistent with the slow, long-term migration of high latitude magnetic fields towards the poles and the cancellation of the polar fields at least once each solar cycle by the opposite polarity fields at lower latitudes.

These results were obtained using two indirect methods of determining the direction of the horizontal component of magnetic fields along the long axis of filaments. These methods depend on relationships of the chromospheric fine structure near filaments, and the fine structure in filaments, to the magnetic field polarities of the photospheric network on both sides of the filaments.

3.9 THE CORRESPONDENCE BETWEEN X-RAY BRIGHT POINTS AND EVOLVING MAGNETIC FEATURES ON THE QUIET SUN

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Abstract

Coronal bright points, first identified as X-ray Bright Points (XBPs), are compact, short-lived, and associated with apparent small-scale bipolar magnetic features. Some previous studies have provided evidence that coronal bright points represent emerging bipoles known as ephemeral active regions while other studies have suggested that the coronal bright points are more likely to be associated with small-scale cancelling bipolar magnetic features which shrink as their line-of-sight magnetic flux is observed to slowly decrease. With the goal of resolving these contradictory results, we have studied more recent sets of XBP and magnetic field data. The X-ray data were obtained during the American Science and Engineering X-ray sounding rocket flights on 15 August and 11 December 1987. Full disk magnetogram were obtained before during and after the X-ray observations at the National Solar Observatory at Kitt Peak. Time-lapse series of videomagnetograms were obtained on multiple fields of view at the Big Bear Solar Observatory. To aid in resolving the discrepancies of earlier studies, we first performed an independent analyses of the XBPs and magnetic features on the full-disk magnetograms and a separate double-blind analyses of the XBPs and the magnetic features on the time-lapse, limited-field magnetograms. We found significant differences in the independent results obtained using these two data sets and these differences could account for some of the earlier discrepancies.
From the analyses of magnetic features common to both data sets, we found that: (1) most young, growing ephemeral regions were not associated with conspicuous XBPs; some ephemeral regions were instead associated with extended rather than point-like X-ray sources, (2) some XBPs were associated with ephemeral regions in their late stages of evolution; the likelihood of association was greater for ephemeral regions which were cancelling with adjacent network or intranetwork magnetic features, (3) the sites of a few XBPs were between the diverging or stationary components of ephemeral regions or nearly stationary network features, (4) the most frequent sites for the XBPs were between converging opposite polarity magnetic features where the magnetic fields were cancelling or in a pre-cancelling stage. The opposite-polarity cancelling or pre-cancelling features consisted of various bipolar and multipolar combinations of network magnetic fields, intranetwork magnetic fields and components of ephemeral regions.

3.10 THE CONVERGING FLUX MODEL FOR X-RAY BRIGHT POINTS AND CANCELLING MAGNETIC FEATURES

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Abstract.

X-Ray bright points are an important part of the solar corona, and therefore of the coronal heating problem. When it was first reaslized that bright points are always situated above opposite polarity magnetic fragments in the photosphere, it was natural to suggest that such fragments represent emerging flux and that an X-ray brint point is caused by reconnection of the emerging flux with an overlying coronal magnetic field. However, a recent important discovery at the Big Bear Solar Observatory is that the magnetic framents of opposite polarity are usually not emerging but are instead coming together and disappearing and so are referred to as cancelling magnetic features. Sometimes a tiny filament is observed to form and erupt at the same time.

A unified model is here proposed which explains these observational features and has several phases:
(I) a *Preinteraction Phase*, in which two photospheric fragments are unconnected magneticlly and begin to approach one another, until eventually oppositely directed fields from the fragments come into contact at a second-order null point;
(II) an *Interaction Phase*, in which the null point becomes an X-point and rises into the corona; an X-ray Bright point is created for typically 8 hours by coronal reconnection driven by the continued approach of the photospheric sources; long hot loops and X -ray jets may be created by the reconnection, and rapid variability in bright point emission may be produced by an impulsive bursty regime of reconnection;
(III) a *Cancellation Phase*, in which a cancelling magnetic feature is produced by photospheric reconnection as the fragments come into contact and decrease in strength; above the cancelling fragments a small filament may form and erupt over typically an hour.

An important role is played by the interaction distance (d), which is proportional to the magnetic flux of the fragments and inversely proportional to the overlying magnetic field strength. It determines the fragment separation at which the Interaction Phase begins and the resulting maximum height of the reconnection point.

It is suggestd that coronal reconnection driven by footpoint motion represents an *elementary heating event* that may be heating normal coronal loops and be at the root of the nanoflare/microflare process. Bright points may well be at the large-scale end of a broad spectrum of events that are heating the solar corona.

3.11 PROPERTIES AND EMERGENCE PATTERNS OF BIPOLAR ACTIVE REGIONS
I. Size Distribution and Emergence Frequency

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Abstract.

Patterns in the properties of bipolar active regions are determined throughout cycle 21. Active regions that emerged on the visible hemisphere were identified on NSO/KP full-disk magnetograms during 29 solar rotations selected from 1975 through 1986. The bipolar active regions are included only once in this sampling; their properties are derived at the time of maximum development. In order to study an unbiased sample over the entire range of areas larger than 2.5 square degrees (or 373 Mm^2), their counts are corrected for size-dependent effects that reduce the chance of their identification.

The size distribution of bipolar active regions is a well-defined function that decreases with increasing size. Except for the smallest regions, the shape of the size distribution is independent of the phase of a cycle, only the scaling factor varies. The shape of the size distribution function for bipoles emerging within existing sunspot regions is virtually the same as that for bipoles emerging outside existing regions. Over the cycle, at least 44% of the regions larger than 3.5 square degrees emerge within existing sunspot regions. Hence, the rate at which new regions emerge is much higher within the boundaries of existing sunspot regions than it is in the activity belts outside existing regions. For regions emerging outside of existing sunspot regions, this rate increases by a factor of 3.5 from cycle minimum to maximum, while for new bipoles within existing active regions, the emergence rate varies with a significantly lower magnitude.

Through the cycle, for regions in all size bins, the emergence frequencies appear to vary in phase. The frequencies increase by a factor of more than 8 from minimum to maximum for regions larger than 3.5 square degrees, but by no more than 4.7 for the smaller regions. Short-term variations in the emergence frequency of regions do not necessarily occur simultaneously for regions of all sizes, implying that the size distribution is variable on time scales of less than six rotations.

3.12 PROPERTIES AND EMERGENCE PATTERNS OF BIPOLAR ACTIVE REGIONS
II. Lifetime, Latitude, and Orientation Distributions

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Abstract

Emergence pattern and other properties of young active regions throughout cycle 21 are determined. Bipoles emerging on the visible hemisphere were identified on NSO/KP full disk magnetograms during 29 solar rotations selected from 1975 through 1986. Regions are included only once in this sampling; most of their properties are derived at the time of maximum development. An unbiased sample over the entire range of areas larger than 2.5 square degrees (373 Mm^2) is approximated by correcting the bipole counts for size-dependent effects that reduce the chance of their identification.

The rise times, from the beginning of emergence until maximum development, are short: no more than 5 days even for the largest bipolar regions in the sample. The rise time is a fraction of the lifetime; this fraction decreases with increasing lifetime. There are positive trends between region size, rise time and lifetime, but for regions of any given size there is a broad range in these time-scales. A substantial fraction of the active regions larger than 18.5 square degrees end their bipolar lives by the emergence of another active region of at least equal size within its confines.

3.13 PROPERTIES AND EMERGENCE PATTERNS OF BIPOLAR ACTIVE REGIONS III. Ephemeral Regions

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Abstract

Specific criteria are used to identify and study ephemeral regions. Small-scale bipolar regions with areas less than 2.5 square degrees (373 Mm^2) were selected in 27 time intervals from 1975 to 1986. Regions were included only once and their counts corrected for several effects that result in reducing their visibility. These data, combined with larger active regions, identified during the same time intervals, are used to compare the characteristics and time-dependent emergence patterns of bipolar regions over a size range extending from the largest bipolar active regions to ephemeral regions.

The number of ephemeral regions varies nearly in phase with active regions; their minimum occurs about one year prior to the cycle minimum defined by sunspot regions. Assuming an average lifetime of 4.4 hours, as many as 2,000 ephemeral regions emerge per day on the Sun. Their numbers increase by a factor of 2.1 from sunspot minimum to maximum, a substantially smaller amplitude than the factor of 8.3 for active regions larger than 3.5 square degrees. Ephemeral regions are observed over most of the solar surface. Their latitude distribution is not uniform; their pattern is a butterfly diagram with extended wings. They show some preference for a proper, low-inclination orientation, though there is a wide range in their orientations.

During the declining phase of cycle 21, a high-latitude (poleward of 30 degrees) component of ephemeral regions develops with a preferential orientation reversed from the lower latitude active regions. These regions are identified with the new cycle and are seen about 2 years after the reversal of the polar magnetic fields and at least 3 years before the occurrence of sunspot minimum of cycle 22 and approximately 2.5 years before the first recognized sunspot regions of cycle 22. Ephemeral regions exhibit many characteristics similar to those of larger active regions, and they continue in a smooth way the size-dependent properties of active regions. It is concluded that ephemeral regions are in the small scale end of a wide size spectrum of bipolar active regions.

3.14 MAGNETIC FIELD CONFIGURATIONS BASIC TO FILAMENT CHANNELS AND FILAMENTS

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Abstract

From analyses of H-alpha chromospheric structure together with line-of-sight photospheric magnetograms, we identify a fundamental rotational magnetic field configuration observed or deduced to be common to all filament channels. The channel is characterized by a nearly horizontal magnetic field along the channel axis where a filament can form in coincidence with the zone between opposite polarity line-of-sight magnetic fields. Orthogonal to the channel axis, and with increasing distance from the axis, the magnetic field direction rotates to gradually increase the outward and inward vertical components of the magnetic field respectively on the two sides of the channel. Two and only two senses of rotation are found and are defined as sinistral and dextral. Filament channels are evidently more fundamental than filaments because the channels are often observed to develop prior to the formation of filaments, to be longer than filaments and to survive the reformation and eruption of successive filaments. Filaments are also sinistral and dextral according to the classification of their channels because the magnetic field component along the long axis of filaments is shown to be in approximately the same direction as the horizontal magnetic field along the axis of the channel. In addition, filaments were found to have two structural variations which relate one-for-one to the sinistral and dextral magnetic configurations. A sample of 82 predominately active region filaments and a sample of 72 filaments representative of the whole sun were analyzed to independently determine their magnetic class and structural class. For quiescent filaments, the dextral magnetic and structural types statistically dominate the northern hemisphere while the sinistral magnetic and structural types dominate the southern hemisphere. However, for active region filaments, no hemispheric pattern was found. From previously published data in the literature and more recent data, it is concluded that the dominance of dextral filaments in the northern hemisphere and sinistral filaments in the southern hemisphere has persisted throughout the current and last 3 solar cycles.

3.15 AN OBSERVATIONAL AND CONCEPTUAL MODEL OF THE MAGNETIC FIELD OF A FILAMENT

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Abstract

A conceptual, scale model of the geometry of the magnetic field of a filament was developed primarily from: (1) the observed structure of a filament recorded in H-alpha filtergrams, (2) calculations of the height of the filament (3) the association of the appendages along the sides of the filament with patches of photospheric magnetic flux opposite in polarity to the network magnetic fields on each side of filament, (4) the observed association of the ends of the filament with network magnetic fields of opposite polarity and (5) the assumption that the fine structure of the filament is parallel to the magnetic field in the filament. The model is consistent with the inverse category of quiescent prominences. The three-dimensional geometry of the model is sufficiently simple that wire is used to represent the imaginary magnetic field lines and their relationship to magnetic flux patches on a magnetogram.

4.0 ABSTRACTS OR SUMMARIES OF PRESENTATIONS

4.1 AN OBSERVATIONAL-CONCEPTUAL MODEL OF THE FORMATION OF FILAMENTS

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Abstract

Examples of the formation of filaments are analyzed from high resolution H-alpha filtergrams from the Big Bear Solar Observatory, the U.S. National Observatory at Sacramento Peak, the Ottawa River Solar Observatory and the Udaipur Solar Observatory along with line-of-sight magnetograms from the Big Bear Solar Observatory and the U.S. National Observatory at Kitt Peak. It is deduced that the magnetic field in the environment of filaments has a rotational configuration that requires depiction in three dimensions and looks like a 'rotational discontinuity' (Spreiter and Alksne, 1969, Reviews of Geophys. 7, 11), a magnetic field geometry that is also commonly observed in the plasmas of the interplanetary medium at some interfaces between oppositely-directed magnetic fields. Evidence for this magnetic field configuration in the environment of filaments comes from the asymmetric rosettes and patterns of the fibrils adjacent to the filaments, from the direction of the structure within and under the filaments, and from the deduced direction of the magnetic fields adjacent to the filaments as they are forming. The directions of motion of the magnetic fields adjacent to the filaments reveal that the asymmetry of the rosettes and direction of the fibrils is not due to the flow pattern of the photospheric magnetic fields adjacent to the filaments. Instead, the asymmetry of the rosettes and patterns of the fibrils are related to the local direction of the magnetic fields in and around the filaments as previously interpreted by Foukal (1971, Solar Phys. 19, 59). Immediately adjacent to filaments, the magnetic field lines from the rosettes are inclined from vertical in planes approximately parallel to the sides of the filaments; they are also inclined in opposite directions from vertical on the two sides of the filaments. In general, the inclinations of the field lines around and in filaments are: (1) in the same general direction as the fibrils that appear to stream from the core of the rosettes or adjacent plage, (2) greatest adjacent to the filaments, decreasing with increasing distance from the sides of the filaments, and (3) 90 degrees (horizontal) in the filament channel. Recognition of this pattern of inclined magnetic fields in the environment of a filament as being like a 'rotational discontinuity' brings new information for consideration in modelling the formation of filaments.

The formation of the filaments coincides with the observed convergence, encounter, and cancellation of knots of magnetic flux of opposite polarity in the horizontal region of a polarity inversion. It is hypothesized that the horizontal magnetic fields in the coronal part of the polarity inversion increase simultaneously with the cancellation observed in the line-of-sight magnetograms It is further hypothesized that these changing magnetic fields occur simultaneously due to a slow type of magnetic field reconnection whose point of

initiation is at or near the photospheric/chromospheric interface and between the oppositely-inclined and opposite polarity magnetic fields which have converged together from the two sides of the filament channel. This proposed configuration of reconnection would result in the conversion of pairs of oppositely-inclined field lines into single, nearly horizontal field lines which rise into the corona, coming to equilibrium as additional field lines in the horizontal, coronal region of the polarity inversion (which would correspond to the middle of a rotational discontinuity). Mass concurrently accumulating in the horizontal part of the polarity inversion, eventually reaches a density and temperature which allows it to be detected as a filament. By means of the proposed reconnection, magnetic and kinetic energy are extracted from regions close to the photospheric-chromospheric interface and stored in the chromospheric and coronal parts of the polarity inversion. The energy stored within the coronal part of the polarity inversion is then available for subsequent release in dynamic coronal events.

Abstract submitted for presentation by S.F. Martin as a poster paper in the Session on 'Prominences' at the IAU meeting in Buenos Aires, Argentina, July 1991 and at the IAU Colloquium on Eruptive Flares in Iguazu, Argentina, August 1991.

4.0 PUBLICATIONS: 1990-1993

4.1 Research Papers - Published

1. 'The Formation of Prominences as Inferred from Optical Observations' by S.F. Martin, *Dynamics of Quiescent Prominences*, Proceedings of the No 117 Colloquium of the International Astronomical Union, Hvar, Yugoslavia 1989, in Lecture Notes in Physics 363, Springer-Verlag (1990)

2. 'Elementary Bipoles of Active Regions and Ephemeral Active Regions' in *Solar Magnetic Fields* (ed. G. Poletto), Mem. S.A.It., 61, 293 (1990)

3. 'The Evolution and Orientation of Early Cycle 22 Active Regions' by A.T. Cannon and W.H. Marquette, *Solar Phys*. (1990)

4. 'Do Changes in the Photospheric Magnetic Network Cause the 11-year Variation of Total Solar Irradiance?' by P. Foukal, K.L. Harvey and F. Hill, Astrophys. J. 383, L89-L92 (1991)

5. 'Measurements of Solar Magnetic Fields as an Indicator of Solar Activity Evolution' by K. L. Harvey, in R.F. Donnelly (ed.), Proceedings of the Workshop on the Solar Electromagnetic Radiation Study for Solar Cycle 22 (SOLERS 22), Boulder, Colorado, June 1991, pp. 113-129 (1992).

6. 'The Role of Cancelling Magnetic Fields in the Eruption of Filaments and Flares', IAU Colloquium 133, *Eruptive Flares,* (eds.) Z Svestka, M. Machado, B. Jackson, IAU Colloquium 133, 2-6 August 1991, Iguazu, Argentina, p 33 (1992)

7. Extended Abstract - 'An Observational-Conceptual Model of the Formation of Filaments' *Eruptive Flares*, (eds.) Z Svestka, M. Machado, B. Jackson, IAU Colloquium 133, 2-6 August 1991, Iguazu, Argentina, p 331 (1992)

8. 'The Cyclic Behavior of Solar Activity' by K. L. Harvey, in K.L. Harvey (ed.), *The Solar Cycle,* ASP Conference Series 27, pp. 335-367 (1992).

9. 'The Solar Cycle Pattern in the Direction of the Magnetic Field Along the Long Axes of Polar Filaments' by S.F. Martin, W.H. Marquette and R. Bilimoria, in *The Solar Cycle,* (ed.) K.L. Harvey, Proceedings of the 12th National Solar Observatory/Sacramento Peak Observatory Summer Workshop, ASP Conference Series, Volume 27, p. 53 (1992)

10. BOOK - *The Solar Cycle* (ed.) Karen L. Harvey, Proceedings of the National Solar Observatory/Sacramento Peak 12th Summer Workshop, ASP Conference Series, 27 (1992)

11. 'The Correspondence Between X-Ray Bright Points and Evolving Magnetic Features' by D.F. Webb (AFGL and Boston College), D. Moses (NRL), S.F. Martin (Caltech) and J.W. Harvey (NSO/Kitt Peak) *Solar Phys* 144, 15

(1993)

12. 'A Converging Flux Model for X-ray Bright Points and Cancelling Magnetic Fields' by E. Priest, J. Parnell, and S.F. Martin, *Astrophys. J.* submitted April 1993 and accepted

13. 'Properties and Emergence Patterns of Bipolar Active Regions. I. Size Distribution and Emergence Frequency' by K. L. Harvey and C. Zwaan, *Solar Phys.* 148, 85-118 (1993).

14. 'Solar Fine-scale Structures in the Corona, Transition Region and Lower Atmosphere' by D. Moses, J.W Cook, J.-D.F. Bartoe, G.E. Brueckner, K.P, Dere (NRL), D.F. Webb (Boston College), J.M. Davis MSFC), J.W. Harvey (NSO/Kitt Peak), F. Recely (NOAA), S.F. Martin (Caltech) and H. Zirin, (Caltech), accepted by Astrophys. J. for 20 July 1994 issue.

4.2 Research Papers - Submitted for Publication

1. 'Magnetic Field Configurations Basic to Filament Channels and Filaments', by S.F. Martin, R. Bilimoria and P.W. Tracadas, submitted to Proceedings of the NATO Workshop on Solar Surface Magnetism, held in Soesterberg, The Netherlands, November 1993, Kluwer Academic Publishers 1994.

2. 'An Observational and Conceptual Model of the Magnetic Field of a Filament' by S.F. Martin and C.R. Echols, submitted to Proceedings of the NATO Workshop on Solar Surface Magnetism, held in Soesterberg, The Netherlands, November 1993, Kluwer Academic Publishers 1994.

4.3 Research Papers in Preparation for Publication

1. 'Properties and Emergence Patterns of Bipolar Active Regions: II. Lifetime, Latitude, and Orientation Distributions', Karen L. Harvey, Solar Physics Research Corporation, Tucson, AZ 85718, U.S.A., To be submitted to *Solar Physics* Journal

2. 'Properties and Emergence Patterns of Bipolar Active Regions: III. Ephemeral Regions', Karen L. Harvey Solar Physics Research Corporation, Tucson, AZ 85718, U.S.A., To be submitted to *Solar Physics* Journal

3. Invited Review Paper on 'The Formation of Prominences' for *Solar Physics,* by S.F. Martin and C. Zwaan, and P. Foukal

5.0 PROFESSIONAL PERSONNEL ASSOCIATED WITH THE PROJECT

1. Sara F. Martin (Principal Investigator)
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5.1 STUDENT ASSISTANTS

1. Undergraduate Assistant - Summers of 1990 and 1991 Rajesh Bilimoria (Caltech)

2. Undergraduate Assistant - Summer of 1992
Philip W. Tracadas (MIT)

3. Undergraduate Assistant - Summer of 1993
Chris Echols (Caltech)

6.0 INTERACTIONS

6.1 Papers Presented at Formal Scientific Meetings and Workshops

1. 'Conditions for the Formation of Prominences as Inferred from Optical Observations', talk given at Max '91 Workshop, Estes Park, CO, June 1990

2. Some Examples of Flares and Erupting Prominences Recorded by NSO, Kitt Peak in 10830, Full-disk Images', informal presentation by S.F. Martin at Max '91 Workshop, Estes Park, CO, June 1990

3. 'The Association of Erupting Prominences to the Birth of Active Regions', informal talk given by S.F. Martin at the Max '91 Workshop, Estes Park, CO, June 1990

4. 'Measurement of Solar Magnetic Fields as an Indicator of Solar Activity Evolution' invited talk by Karen L. Harvey at the SOLERS22 Workshop, Boulder, CO,3-7 June 1991.

5. ' An Observational Conceptual Model of the Formation of Filaments' by S.F. Martin, Poster Paper presented at IAU General Assembly, July 1991, Buenos Aires, Argentina and at the IAU Colloquium 133 on Eruptive Flares in Iguazu, Argentina, 2-6 Aug. 1991.

6. 'The Role of Cancelling Magnetic Fields in the Eruption of Filaments and Flares' by S.F. Martin and S.H.B. Livi at IAU Colloquium 133 on Eruptive Flares, 2-6 Aug. 1991, Iguazu, Argentina.

7. 'The Cyclic Behavior of Solar Activity' by Karen Harvey at the 4th Solar Cycle Workshop, National Solar Observatory/Sacramento Peak Observatory 12th Summer Workshop, Oct. 1991

8. 'The Solar Cycle Pattern in Polar Crown Prominences' S.F. Martin, W.H. Marquette and R. Bilimoria presented a Poster Paper on the at the 4th Solar Cycle Workshop, Sacramento Peak Observatory, October 1991

9. 'The Solar Cycle Pattern in the Direction of the Magnetic Field Along the Long Axes of Polar Filaments' by S.F. Martin, W.H. Marquette and R. Bilimoria, a Poster Paper at the 4th Solar Cycle Workshop, National Solar Observatory/Sacramento Peak Observatory 12th Summer Workshop, Oct. 1991

10. 'Magnetic Field Configurations Basic to Filament Channels and Filaments, SPD Meeting Paper, Stanford Univ., Stanford CA, July 1993

11. 'Observational Criteria for Filament Models' by S.F. Martin, NSO/Sacramento Peak 14th Summer Workshop, August 1993

12. Talk by Karen Harvey at NATO Workshop on Solar Surface Magnetism, Soesterberg, The Netherlands, Nov. 1993

13. 'Network and Intranetwork Magnetic Fields' by S.F. Martin at NATO Workshop on Solar Surface Magnetism, Soesterberg, The Netherlands, Nov. 1993

6.2 Other Scientific Presentations

1. 'Predicting the Maximum of Solar Cycle 22 and other Solar Cycle Parameters', contribution to the NASA Working Group on Solar Terrestrial Prediction by Karen L. Harvey, Huntsville, Alabama, 8-9 Nov. 1989

2. 'Conditions for the Formation of Prominences as Inferred from Optical Observations', talk given by S.F. Martin at Solar Neighborhood meeting Dec 1989, Stanford, CA

6.3 Other Scientific Interactions

1. S.F. Martin attended SPD Meeting of AAS, April 1991, Huntsville, AL

2. Karen Harvey attended AAS Meeting in Columbus, Ohio

3. S.F. Martin gave talk at Sacramento Peak Observatory on 'The Formation of Filaments' October 1991

4. S.F. Martin gave two talks at Goddard Space Flight Center, May 1992 on The Formation of Filaments and The Eruption of Filaments

5. S.F. Martin gave 2 Informal Presentations at Flares22 Workshop, Ottawa Canada, May 1992

6. S.F. Martin gave a Colloquium Talk at the Herzberg Institute off Astrophysics, Ottawa Canada, June 1993 on 'Magnetic Field Configurations Basic to Filament Channels and Filaments'

7. S.F. Martin gave a Colloquium Talk at NOAA, Boulder CO, July 1993 on 'Magnetic Field Configurations Basic to Filament Channels and Filaments'